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VERDIGRIS RIVER INVESTIGATION KANSAS
AND OKLAHOMA: WATER SUPPLY AND POLLU-
TION ABATEMENT FLOWS REQUIRED AND
MONETARY BENEFITS

M. LeBosquet, Jr.

Public Health Service
Cincinnati, Ohio

June 1944

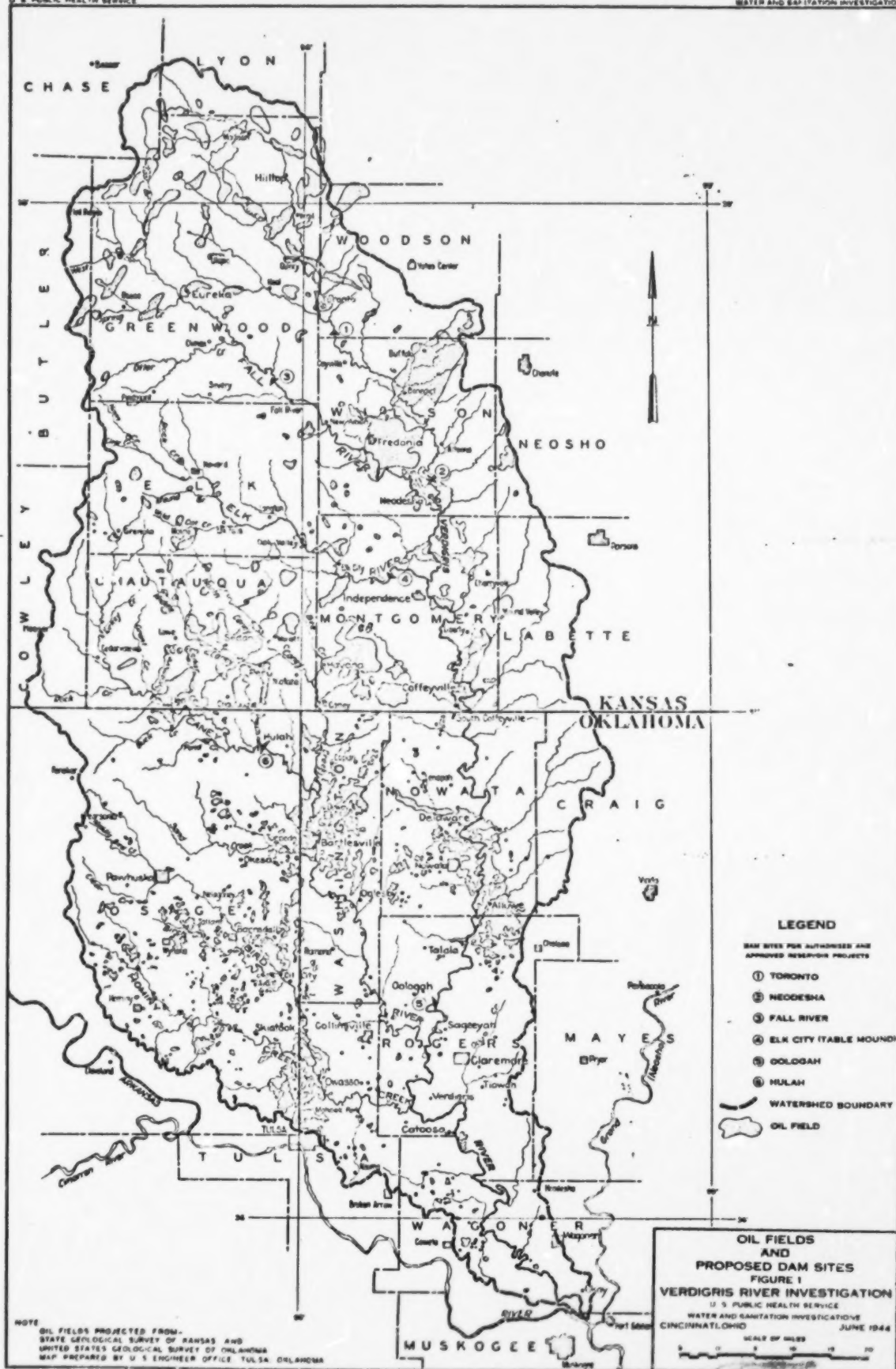
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U. S. PUBLIC HEALTH SERVICE
Water and Sanitation Investigations
Cincinnati, Ohio
June, 1944

VERDIGRIS RIVER INVESTIGATION
KANSAS AND OKLAHOMA

Water Supply and Pollution Abatement
Flows Required and Monetary Benefits

By

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Prepared by the U. S. Public Health Service
at the request of the Chief of Engineers,
U. S. Army, in co-operation with the
District Engineer, United States Engineer
Office, Tulsa, Oklahoma.

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Introduction

The Office of the Chief of Engineers, U. S. Army, in a communication dated June 2, 1943, requested that the U. S. Public Health Service co-operate on a reimbursable basis with the Division Engineer, Southwestern Division, Dallas, Texas, and the District Engineer, Tulsa, Oklahoma, in connection with a determination of reservoir capacities that should be reserved for water supply and pollution abatement purposes in the Verdigris River Basin of Oklahoma and Kansas. Under date of June 8, 1943, the Surgeon General of the U. S. Public Health Service accepted the assignment. Under date of June 14, 1943, the proposed study was outlined, and this study was approved by the District Engineer on June 19, 1943.

Under date of December 13, 1943, the U. S. Public Health Service suggested that the scope of the study be expanded to include possible malaria hazards. The District Engineer expressed an interest in the suggestion and referred the matter to higher authority. However, the District Engineer did not consider such studies to be pertinent to the purpose of the report at that time, and accordingly malaria hazards are not considered herein.

The reservoir projects under present consideration were included in a report transmitted under date of July 19, 1939, and printed as House Document No. 440, 76th Congress, 1st Session. The projects were approved by the Flood Control Act of August 18, 1941. As these projects are now approved for construction and no further economic justification is required at this time, the present assignment has to do primarily with the magnitude of conservation flows to be provided rather than the

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financial value of such flows. However, the District Engineer's Office has requested that very brief consideration be given to benefits, and that approximate estimates be included.

Previous U. S. Public Health Service investigations for the District Engineer, Tulsa, Oklahoma, District have included a study of the adequacy of proposed conservation storage capacities to deliver the flows necessary for water supply and pollution abatement. By agreement with the U. S. Engineer Office, the present investigation has been confined to estimation of required flows and benefits, leaving to the U. S. Engineer Office the hydrometric studies of the adequacy of proposed conservation storage capacities.

The request from the Office of the Chief of Engineers specifically mentioned the approved Toronto, Neodesha, Fall River, and Elk River Reservoirs. In addition, the District Engineer's Office requested that consideration be given to Oologah Reservoir and to all the principal tributaries in the Verdigris River basin. This latter request added the approved Oologah Reservoir on Verdigris River, the authorized Mulah Reservoir on Caney River, and a possible project on Bird Creek, to the scope of the investigation.

The study has been carried on with the close co-operation of the Tulsa District Engineer Office, and that office has furnished detailed hydrometric data, and has prepared tabulations and charts.

Data on reservoirs under consideration at the present time and included in the plan for the Verdigris River basin are shown in Table 1. Reservoir locations are shown on Figure 1.

Table 1 - Verdigris River Investigation - Data on Reservoirs.

Reservoir	Tributary Stream	Miles to mouth		Storage, Acre-foot		Area		Status
		Verdigris River	Tributary Stream	Flood Control	Conser- vation	Total	max. pool, acres	
Oologah	Verdigris	90.2	-	950,000	25,000(1)	975,000(1)	41,900(1)	Approved
Toronto	Verdigris	271.5	-	140,000	20,000	160,000	6,900	Approved
Neodesha	Verdigris	222.8	-	80,000	10,000	90,000	7,100	Approved
Hulah	Caney	174.7	96.2	280,000	15,000	295,000	13,000	Authorized
Fall River	Fall	269.5	54.2	224,000	39,000	263,000	10,400	Approved
Elk City (Table Mound)	Elk	206.6	8.7	236,000	14,000	250,000	17,600	Approved
Total				1,910,000	123,000	2,033,000	90,900	

(1) Approved project.

Conclusions

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(1) There are 20 municipal water supplies in the Verdigris River basin obtained from surface sources (Table 4), representing an average consumption of 9.8 million gallons per day. Ten of these supplies, representing an average consumption of 7.4 million gallons per day, or 76 per cent of the total, are below proposed dam sites and will be benefited by proposed developments. Two additional surface supplies are obtained from Bird Creek and its tributaries and, depending on the project location, might be benefited by a Bird Creek development.

(2) Oil refineries at Coffeyville and Neodesha, Kansas, use a total of 25 million gallons per day from Verdigris River.

(3) Sewage from a population of 107,500 and industrial wastes with a sewered population equivalent of 25,600 (Table 5) are produced in the Verdigris River basin. Treatment in municipal treatment plants reduces the total pollution load of 133,100 to 61,100, a reduction of 54 per cent. Practically all of the cities have sewage treatment plants, although many are inadequate or less efficient than desirable.

(4) Chloride results on samples from public water supplies (Table 7) indicate progressive increases in averages due to increasing discharge of oil field brines up until 1936-1939, since which time there has been a marked decrease attributable to successful brine disposal efforts by reinjection into oil sands through disposal wells.

(5) Taste and odor difficulties in municipal surface water supplies in the basin due to industrial wastes and to algae are reported to occur at intervals, although no systematic record is available.

(6) Useful flows in Verdigris River at Coffeyville, Kansas, for municipal and industrial water supply, for the maintenance of municipal water supply quality and to assist in the abatement of pollution, vary from 51 c.f.s.* (Schedule "B") in July and August to 24 c.f.s.* from November to March (annual average 32 c.f.s.*). Useful flows at other points and individual monthly variations are shown in Tables 10 and 11. The reach of the Verdigris River below Oologah Reservoir is remote from sources of pollution and is not used as the source of an important local water supply. Therefore, releases from this reservoir need not be governed by questions of pollution or local water supply.

* Except during unusually dry years occurring no oftener than once in ten years. Eighty per cent of indicated flows, however, should be guaranteed during such unfavorably dry years.

(7) Monetary benefits resulting from proposed developments capable of providing the indicated useful flows (Schedule "B") total \$284,900 per year, of which \$185,600 per year is a benefit from the four Kansas reservoirs (Toronto, Neodesha, Fall River and Elk City), \$85,600 per year is a benefit from Hulah Reservoir and \$13,700 per year is a benefit from a possible project on Bird Creek. No tangible monetary pollution or local water supply benefits can be credited to Oologah Reservoir.

(8) Useful flows to provide municipal water supply quantity requirements only (Schedule "A") and useful flows to assist in pollution abatement to a greater degree (Schedule "C"), together with monetary benefits resulting from such flows, are shown in Tables 10 and 12.

(9) Equally important benefits to agriculture, to aquatic and wild life, to recreation and to the public health, will result from the proposed developments.

Description

7.

The Verdigris River is 351 miles long from its source in Chase County, Kansas, to its confluence with the Arkansas River near Muskogee, Oklahoma. The river flows in a generally southerly direction for a distance of 189 miles in Kansas and 162 miles in Oklahoma.

The largest tributaries, all entering from the west, are the Fall and Elk Rivers entering in Kansas, and Caney River and Bird Creek entering in Oklahoma. Data on the principal tributaries are given in table 2.

The largest city in the vicinity is Tulsa, Oklahoma. (1940 population 142,157), a minor portion of which is in the drainage area of the Verdigris River. The sewage from 24,000 of Tulsa's population discharges to Bird Creek after receiving secondary treatment. The largest cities wholly within the basin are Coffeyville and Independence, Kansas, on the main Verdigris River, and Bartlesville, Oklahoma, on the tributary Caney River. U. S. Census population figures for some of the principal communities in the Verdigris River Basin are shown in table 3.

Table 3 - Vordigris River Investigation - U. S. Census Population of
Larger Cities.

City	P o p u l a t i o n			
	1910	1920	1930	1940
Coffeyville, Kan.	12,687	13,452	16,198	17,355
Bartlesville, Okla.	6,181	11,417	11,763	16,267
Independence, Kan.	10,480	11,920	12,782	11,565
Pawhuska, Okla.	2,776	6,414	5,931	5,443
Claremore, Okla.	2,866	3,435	3,720	4,134
Nowata, Okla.	3,672	4,435	3,531	3,904
Eureka, Kan.	2,333	2,606	3,698	3,803
Wagoner, Okla.	4,018	3,436	2,994	3,535
Fredonia, Kan.	3,040	3,954	3,446	3,524
Neodesha, Kan.	2,872	3,943	3,381	3,376
Cherryvale, Kan.	4,304	4,698	4,251	3,185
Caney, Kan.	3,597	3,427	2,794	2,629

The area of the Verdigris River Basin includes some of the first oil producing properties in Oklahoma and Kansas. As an expected result, there has been a history of oil and brine pollution and pollution from oil refineries in addition to normally expected domestic sewage and miscellaneous industrial pollution. The location of present oil fields as obtained from oil maps of Oklahoma and Kansas is indicated on figure 1.

Survey Methods

In view of the present war situation, a comprehensive investigation of the pollution problems of the Verdigris River Basin was considered neither possible, justified nor necessary for present purposes. The present investigation, therefore, has consisted primarily of the assembly, tabulation, presentation and study of existing information. Four different types of information have been considered, as follows:

- (1) Temperature records
- (2) Data on surface water supplies and sources of pollution.
- (3) Laboratory data.
- (4) Hydrometric data.

Temperature records are important as they are one of the principal determining factors governing dilution requirements for pollution control from the standpoint of maintaining satisfactory levels of dissolved oxygen. Temperatures also have a bearing on the rapidity with which taste- and odor-producing substances are rendered inoffensive through the action of natural purification agencies.

Data on public surface water supplies and sewage pollution were obtained from a "Census of Water Treatment Plants" and a "Census of Sewer Systems and Sewage Treatment Plants", presenting information collected by the various state health departments and tabulated by the Water and Sanitation Investigations Station of the U. S. Public Health Service. The state health departments of Oklahoma and Kansas were particularly helpful in checking this information, bringing it up to date, and indicating the degree of efficiency being obtained by the various municipal sewage treatment plants.

Estimates of industrial waste pollution loads have been obtained from information collected chiefly by the District Engineer's Office on the type and magnitude of the various industrial plants. In this connection, information is available in the U. S. Public Health Service records, particularly on the Ohio River Pollution Survey, in regard to unit pollution loads normally expected from various types of industry.

Laboratory results considered have been confined largely to chloride results obtained on samples collected by the various public surface water supplies of the basin. These results were obtained in part from the records of the water treatment plants themselves and in part from the records of the State Health Departments of Oklahoma and Kansas.

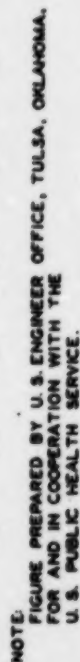
No analytical results were found to give data on oxygen conditions in the Verdigris River Basin. Previous results on other streams, however, serve as a basis for estimating the effect of changes in flow on oxygen conditions, and it is believed that conclusions reached are reliable.

Hydrometric data compiled by the District Engineer's Office from their own and U. S. Geological Survey records include tabulations of monthly average flows and data on gaging stations from which times of flow between various points can be estimated.

Figure 2 shows the location and magnitude of the principal sources of pollution in the Verdigris River Basin. The pollution loads as indicated are in terms of biochemical oxygen demand and reflect neither the magnitude of taste and odor producing discharges nor the magnitude of residual chloride discharge with oil field brines escaping other methods of disposal. For purposes of clarity, only the greatly significant sources of pollution have been indicated. Other items shown include water supply intakes, and the location of reservoirs now being given consideration.

Public Water Supplies

As indicated in table 4, there are 20 public water supplies in the Verdigris River Basin that are taken principally from surface sources. These serve a population of 80,700 people with an average of 9,760,000 gallons of water daily. Ten of these supplies, serving a population of 58,200 with an average of 7,420,000 gallons of water daily, will be affected by the proposed reservoirs. This comprises 76 per cent of water delivered by public water supplies from surface sources in the basin. The principal supplies affected are those at Coffeyville and Independence, Kansas, and Bartlesville, Oklahoma, whose combined delivery averages 5,100,000 gallons per day or 69 per cent of the public water supply affected and 52 per cent of the total surface public water supply.



**SOURCES OF POLLUTION
AND
MUNICIPAL WATER SUPPLY INTAKES
FIGURE 2
VERDIGRIS RIVER INVESTIGATION
U. S. PUBLIC HEALTH SERVICE
WATER AND SANITATION INVESTIGATIONS
CINCINNATI, OHIO
JUNE 1944**

Table 4 - Verdigris River Investigation - Municipal
Surface Water Supplies Taken from
Verdigris River and Its Tributaries.

Stream and Municipality	State	Mile (1)	Treat- ment (2)	Popu- lation served	Average Consumption, M.G.D.
Verdigris River					
<u>TORONTO DAM SITE</u>		271.5			
Altoona	Kans.	231.5	FD	700	0.02
<u>NEODESHA DAM SITE</u>		222.8			
Fall River		215.3			
Bureka	Kans.	297.3	HD	3,600	.3
<u>FALL RIVER DAM SITE</u>		269.5			
Fredonia	Kans.	241.3	HD	3,400	.5
Neodesha	Kans.	220.9	HD	3,200	.8
Verdigris River					
Cherryvale	Kans.	201.4	HD	3,000	.3
Elk River		197.9			
Howard	Kans.	267.4	FD	1,100	.1
Wildcat Creek		254.4			
Moline	Kans.	263.1	FD	800	.1
Longton	Kans.	244.9	FD	500	.02
Elk City	Kans.	225.9	FD	600	.02
<u>ELK CITY DAM SITE</u>		206.6			
Verdigris River					
Independence	Kans.	195.0	FD	11,000	1.8
Coffeyville	Kans.	165.0	HD	13,000	2.0
Nowata	Okla.	122.2	FD	3,900	.4
<u>OCLOGAH DAM SITE</u>		90.2			
Caney River		78.5			
Caney Creek		159.0			
Sedan	Kans.	197.7	FD	1,800	.2
Caney	Kans.	176.5	FD	2,500	.2
<u>HULAH DAM SITE</u>		174.7			
Dewey	Okla.	154.0	FD	2,100	.2
Bartlesville	Okla.	148.0	FD	16,000	1.3
Collinsville	Okla.	93.9	FD	1,900	.1
Bird Creek		63.5			
Pawhuska	Okla.	145.4	FD	5,400	.8
Barnsdall	Okla.	111.0	FD	1,800	.1
Dog Creek		54.8			
Claremore	Okla.	68.7	FD	4,100	.5
TOTAL				80,400	9.76

(1) Miles to mouth of Verdigris River

(2) F - Coagulated, settled, filtered

H - Softened

D - Chlorinated.

Industrial Water Supplies

Limited data on industrial water supplies indicate that industrial water use is important to the oil refineries at Coffeyville and Neodesha, Kansas. These refineries, combined, use an estimated average total of 25,000,000 gallons per day (39 c.f.s.). As the flow in the stream is quite often less than this figure, the industries find it necessary to repump and reuse a considerable portion of their supply.

Sources of Pollution

Table 5 summarizes the location and magnitude of significant sources of organic pollution, including industrial wastes discharged to streams in the Verdigris River Basin. The total pollution load prior to treatment has a sewered population equivalent of 133,100 of which 107,500 is from population connected to sewers and 25,600 is from industrial wastes.

The total pollution load is reduced from 133,100 to 61,100 sewered population equivalent by treatment in municipal sewage treatment plants, or a reduction of 54 per cent. The reduction in pollution by treatment as indicated in table 5 is accomplished by municipal plants. The sewage from 89 per cent of the sewered population receives treatment to a greater degree than septic tank treatment. The percentages receiving primary and secondary treatment are 5 and 84 respectively. While in general the degree of sewage treatment is adequate, this is not always the case and some of the secondary treatment plants are in such a condition or of such adequacy as to be more accurately described as partial treatment plants rather than secondary treatment plants.

Table 5 - Verdigris River Investigation - Sources of Pollution Including Industrial Wastes Expressed as Sewered Population Equivalent (A.O.D.) Discharging to Verdigris River and Its Tributaries.

Stream and Municipality	State	Mile (1)	Population connected to sewers	Treatment (sewage only)	Sewered population equivalent (A.O.D.)	
					Untreated	Discharged
Verdigris River						
Madison	Kans.	325.7	1,000	Secondary	1,000	800
Toronto	Kans.	279.0	500	Secondary	500	300
<u>TORONTO DAM SITE</u>		271.5				
<u>NEODESHA DAM SITE</u>		222.8				
Neodesha	Kans.	219.0	2,700	Secondary	9,000	7,800
Fall River						
Eureka	Kans.	215.3				
<u>FALL RIVER DAM SITE</u>		207.3	3,000	Septic T.	3,000	3,000
Fredonia	Kans.	209.6				
	Kans.	241.3	3,200	Secondary	3,200	600
Elk River						
Howard	Kans.	197.9				
Wildcat Creek	Kans.	207.4	800	Secondary	800	500
Moline	Kans.	264.4				
<u>ELK CITY DAM SITE</u>		263.1	700	Secondary	700	300
(Table Mound)		265.6				
Verdigris River						
Independence	Kans.	195.0	10,000	Secondary	10,000	2,800
Drum Creek						
Cherryvale	Kans.	190.9				
	Kans.	197.4	2,600	Secondary	2,600	1,000
Verdigris River						
Coffeyville	Kans.	165.0	17,000	Secondary	20,000	16,400
Western Branch						
Nowata	Okla.	125.7				
	Okla.	129.8	3,600	Secondary	3,600	700
Verdigris River						
<u>COLOGAN DAM SITE</u>		90.2				
Caney River						
Caney Creek		78.5				
Sedan	Kans.	159.0				
Caney	Kans.	197.7	1,600	Secondary	1,600	600
Cedarvale	Kans.	176.5	2,200	None	2,200	2,200
Elgin	Kans.	206.2	800	Secondary	800	400
<u>HULAN DAM SITE</u>		196.3	300	Primary	300	200
Bewey		174.7				
Bartlesville	Okla.	154.0	2,100	Secondary	2,100	400
Collinsville	Okla.	148.0	15,000	Secondary	15,000	3,000
	Okla.	93.9	1,600	None	1,600	1,600
Bird Creek						
Pawhuska	Okla.	83.5				
Tallmont	Okla.	145.4	5,000	Secondary	5,000	1,000
Barnesville	Okla.	132.4	-	None	2,000	2,000
Skiatook	Okla.	111.0	1,800	Septic T.	5,800	5,800
Tulsa (part)	Okla.	99.6	1,300	Primary	1,300	1,300
	Okla.	80.0	24,000	Secondary	24,000	2,000
Dog Creek						
Claremore	Okla.	54.8				
	Okla.	68.7	3,700	Primary	3,700	3,200
Coal Creek						
Wagoner	Okla.	11.2				
	Okla.	18.8	3,000	Septic T.	3,000	3,000
TOTAL			107,600		133,100	21,100

(1) Miles to mouth Verdigris.

Reduction of industrial waste pollution by corrective measures at the industrial plants is not included in table 5. This is not due to the fact that no corrective measures have been taken but rather because reduction of industrial waste pollution is difficult to estimate in the absence of analytical data collected before and after corrective measures are instituted. One of the most popular methods of minimizing the effect of industrial wastes, if not actually eliminating the pollution, is the use of holding ponds. Such ponds are used for oil field brines and for oil refinery waste. During times of low stream flow, the objectionable waters are stored in holding ponds for later discharge at times of high water.

The present trend in the disposal of oil field brines is toward treatment for clarification of the brines, followed by reinjection into the oil sand through a disposal well or wells. This method is generally considered satisfactory. The development of flooding or repressuring techniques is promising from the standpoint of oil field brine pollution. The brine can be used to advantage for such a purpose and may be more advantageous than surface water for repressuring. The quality of brine is subject to very little change and the most effective treatment prior to injection when once determined can be maintained with very little change.

An unfortunate occurrence in connection with brine pollution took place in the Verdigris River Basin in March, 1938. The 19th Biennial report (July 1, 1936, to June 30, 1938) of the Kansas State Board of Health describes the occurrence as follows:

"The most serious pollution of a major stream by brine occurred during the early part of March, 1938. Rains fell in the watershed of the Verdigris River, flushing out small nonflowing tributaries which had an accumulation of brines in water holes, received illegally from lease ponds extending over a six-month period. The rains were not of sufficient duration or intensity to cause a semiflood stage in the river, consequently these accumulated brines moved slowly down the main channel, causing havoc to the water supplies of those cities dependent upon the Verdigris River. Much adverse publicity was directed against the oil operators in the drainage area, and with cause. This department worked with the city officials of the towns involved in securing a general cleanup and in devising ways and means for the eradication of careless disposal of oil-field brines."

Laboratory Results

Available laboratory results of interest in connection with the present investigation are confined to chloride determination. Many of the water plants test for chlorides as a routine matter and these records have been gathered. Publication No. 52 of the Engineering Experiment Station, Stillwater, Oklahoma, entitled "The Chemical Analyses of the Waters of Oklahoma" and dated October, 1942, furnishes valuable chloride results for the State of Oklahoma. The State of Kansas examines samples from all public water supplies of the state and this examination includes a chloride determination. Inasmuch as many of the supplies are examined at weekly intervals, the results constitute a valuable source of information.

Unfortunately, records of water quality from the standpoint of tastes and odors in water supplies and the standpoint of oxygen conditions, are lacking. Conclusions can be drawn relative to oxygen conditions from the records of a great many similar streams on which data

are available. From the standpoint of taste and odor, conclusions drawn in the absence of detailed local data are less reliable. However, general experience is available on the tastes and odors resulting from oil refinery wastes.

Table 6 presents maximum, minimum and average results of chloride determinations on samples from public surface water supplies. For purposes of comparison, the Public Health Service Drinking Water Standard of 250 p.p.m. (parts per million) is of interest. The averages in Table 6 are all below 250 p.p.m. except the earlier results at Bartlesville, Oklahoma. Recent average results at Bartlesville are less than 250 p.p.m.

Maximum results show that 250 p.p.m. has been exceeded in most of the supplies. This would be true to a greater extent if earlier results at Nowata, Oklahoma, and Cancy and Elk City, Kansas, were considered. Long-time records were collected only at principal points in the basin. For example, results at Independence, Kansas, are available but are similar to those at Coffeyville, Kansas, and have not been summarized.

In considering maximum results, the following statement from the Oklahoma Publication No. 52 is of interest:

"The standard set by the United States Public Health Service of 250 p.p.m. of chloride or 412 p.p.m. of salt (24 g.p.g.) is too low for the average water supply in parts of the state where much higher concentrations of salt are often found. The average individual, adjusted to the use of water of low salt concentration, begins to notice the salty taste at 300 to 400 p.p.m. and, in many cases, the water commences to become objectionable when the concentration is much above these limits. Water with 600 p.p.m. of chloride, or 990 p.p.m. of salt, NaCl, is being used and the people do not find this concentration too displeasing after they become accustomed to it."

Table 6 - Verdigris River Investigation - Maximum, Minimum and Average Chloride Results on Surface Water Supplies

Stream and Municipality	Mile (1)	Number of samples	Dates	Chlorides, p.p.m.		
				Maxi- mum	Mini- mum	Aver- age
Verdigris River						
Claremore, Okla. (2)	75.9	5 (a)	1923-30	420	96	177
<u>COLOGAN DAM SITE</u>	90.2					
Nowata, Okla.	122.2	28 (a)	1925-37	248	83	139
(3)	122.2	19 (c)	1942-43	172	55	111
Coffeyville, Kans.	165.0	528 (b)	1933-43	1040	13	121
<u>NEODESHA DAM SITE</u>	222.8					
Altoona, Kans.	231.5	690 (b)	1930-43	1450	10	135
<u>TORONTO DAM SITE</u>	271.5					
Bird Creek	63.5					
Barnsdall, Okla.	111.0	3 (a)	1923-28	246	33	121
Pawhuska, Okla.	145.4	8 (a)	1924-38	210	20	104
Caney River	78.5					
Bartlesville, Okla.	148.0	35 (a)	1923-37	1160	19	365
" "	148.0	889 (c)	1941-43	380	0	86
<u>HULAH DAM SITE</u>	174.7					
Caney Creek	159.0					
Caney, Kans.	176.5	81 (b)	1942-43	217	32	104
Elk River	197.9					
<u>ELK CITY DAM SITE</u>	206.6					
(Table Mound)						
Elk City, Kans.	225.9	80 (b)	1942-43	202	42	115
Fall River	215.3					
Neodesha, Kans.	220.9	493 (b)	1933-43	460	24	112
<u>FALL RIVER DAM SITE</u>	269.5					

Note. Data is from: (a) Publication No. 52, Engineering Experiment Station, Stillwater, Okla. (b) State of Kansas, and (c) water plant records.

- (1) Miles to mouth, Verdigris River.
- (2) Claremore, Okla., has since abandoned Verdigris River and gone to Dog Creek for its water supply.
- (3) Nowata, Okla. - Monthly averages.

Maximum results above the 400 and 600 p.p.m. figures mentioned have been obtained, the highest figures having been obtained during the unfortunate occurrence of brine pollution in 1938 already described.

Table 7 presents annual chloride results from 1930 to the present according to the records of the Kansas State Board of Health. The table is striking in showing that before a time varying from 1936 to 1939 there was a gradual increase in the average chloride content of the three water supplies included in the tabulation. Since that time there has been a progressive decrease in chlorides. The increase was due to increasing brine discharges, and the later decrease has been due to the effectiveness of corrective measures.

Hydrometric Data

Hydrometric data assembled and tabulated by the Tulsa District U. S. Engineer Office include mean monthly discharges for the principal gaging stations in the Verdigris River basin for the period of record. Table 8 shows the mean monthly flows during the critical 1939-1940 low-water period.

A brief study has been made of the frequency of low monthly flows during the period of record. A summary of the results of this study is shown in table 9. A consideration of the frequency of minimum flows is of considerable interest in connection with pollution studies, as an indication is obtained of the frequency with which objectionable conditions of various magnitudes have occurred in the past. In computing low monthly flow frequencies the lowest monthly flow only for each year

of record is used. By this method, each dry period is counted but once and the method is somewhat similar to that used in determining flood frequencies. There is practically never more than one distinctly dry period during the year. In the present instance, water years have been used to avoid counting the 1939-40 drouth more than once.

Table 7 - Veroigris River Investigation - Annual Maximum, Minimum and Average Chloride Results on Surface Water Supplies

Year	Coffeyville, Kansas.				Altoona, Kansas				Neodesha, Kansas.			
	Number of samples	Chlorides, p.p.m.			Number of samples	Chlorides, p.p.m.			Number of samples	Chlorides, p.p.m.		
		Maxi- mum	Mini- mum	Aver- age		Maxi- mum	Mini- mum	Aver- age		Maxi- mum	Mini- mum	Aver- age
1930					49	1450	94	292				
1931					53	510	100	237				
1932					51	245	101	175				
1933	26	185	36	91	52	329	65	178	9	79	30	59
1934	52	240	38	124	49	375	95	216	50	178	30	96
1935	51	250	26	135	52	617	64	248	53	345	38	130
1936	50	263	60	161	50	473	81	266	49	200	44	124
1937	53	264	12	109	52	640	106	217	55	184	32	82
1938	52	1040	37	159	52	925	71	212	50	210	24	109
1939	53	311	62	177	51	314	10	133	52	460	81	181
1940	52	294	17	120	48	194	19	71	49	240	34	128
1941	53	240	25	105	51	224	52	120	49	162	44	95
1942	54	133	14	71	49	160	45	87	48	190	31	76
1943	32	118	13	75	31	126	41	89	29	112	29	72
Summary	528	1040	13	121	690	1450	10	185	493	460	24	112

Note: Data from Kansas State Board of Health.

Table 3 - Verdigris River Investigation - Monthly Mean Flows During Critical 1939-1940 Low-Flow Period.

River Location Piver miles above: Confluence with Verdigris Mouth of Verdigris Drainage area, square miles Period of record	Verdigris River		Bird Cr. Sperry	Quincy R. Pulaski	Elk R. Elk City	Fall R. Fredonia
	Sagevash	Independence				
	- 82.0 4305 1938-34, 1938-43	- 195.0 2952 1922-42	28.0 91.5 890 1928-32 1936-42	92.5 171.0 750 1938-43	28.0 225.9 577 1938-43	26.0 241.3 816 1938-42
Mean monthly flow (c.f.s.)						
1939	January	31	20.4	5	8.1	31
	February	29	14.2	5	9.8	23
	March	114	40.1	32	35.5	35
	April	925	605	168	260	138
	May	3050	1074	174	350	171
	June	1350	608	67	195	208
	July	180	39.2	9	6.0	15
	August	25	20.3	1	1.8	24
	September	11	.2	0	.1	.5
	October	0	0	0	0	0
	November	0	0	0	0	0
	December	0	0	0	0	1.2
1940	January	0	.8	0	0	0
	February	5	5.5	0	.4	.8
	March	5	1.4	1	.7	5.8
	April	1483	148	101	55	498
	May	1766	137	45	101	317
	June	712	218	394	76	81
	July	635	48	114	1.3	1.5
	August	962	99	51	29	44
	September	1519	581	47	2.8	25
	October	44	1.7	0	.9	.9
	November	2115	620	99	118	84
	December	952	76	64	55	79

Table 9 - Verdigris River Investigation - Low Flow Frequency.

Stream and Location	Miles to mouth of Verdigris River	Years of record	Drainage area, square miles	Minimum monthly mean flows in cubic feet per second that may be expected once in			
				2 years	3 years	5 years	10 years Minimum
Verdigris River							
Catoosa	61.0	6 (1)	7,680	70	33	15	4
Sagecynah	82.0	13	4,305	50	26	12	4
Independence	195.0	21	2,952	24	12	5	1.0
Bird Creek	63.5						
Owasso	87.2	11	1,000	18	8	2.5	.9
Caney River	78.5						
Collinsville	93.9	8	2,090	10	4	1.0	0
Hulah	171.0	6	750	5	2	0	0
Elk River	197.9						
Elk City	225.7	4	577	7	3	.5	0
Fall River	245.3						
Fredonia	241.3	4	816	9	3	.5	0

(1) Record expanded by comparison with flows at Independence, Kansas.

An examination of flow records of the Verdigris River discloses (Tables 8 and 9) that there have been periods of from two to as long as six months when there has been no natural flow whatever in the streams of the basin. This situation has created great hardship and there is an urgent need for conservation and utilization of all water resources in the basin. While the present report attempts to determine certain minimum flows and the monetary value thereof, the need is so great that customary criteria do not apply. The development of water resources is essential to the future of the basin and most important, therefore, is a determination of the wisest and most economical water development.

Table 10 presents a summary of useful minimum flows for various purposes. In designing sewage and industrial waste disposal facilities, it is not usually considered economical to make provision for correcting pollution during times of the minimum flow of record. The expenditures necessary to furnish a purification efficiency used at very infrequent intervals are difficult to justify. A treatment plant designed to be capable of correcting pollution except during unusually dry years occurring no oftener than once in ten years offers a reasonable basis for computation. Even during the driest year of record, a plant so designed would result in a large measure of stream improvement. Applying the same policy to the designation of required flows, it is concluded that the flows indicated should be provided except during unusually dry years occurring no oftener than once in ten years. Eighty percent of indicated flows, however, should be guaranteed during such unfavorably dry years.

Table 10 - Verdigris River Investigation - Useful Minimum Flows for Various Purposes
(Cubic Feet per Second)

River and location	State	Mile (1)	Water supply		Pollution abatement				Conclusions			
			Quantity requirements Schedule #1*	Require- ments to maintain quality Schedule #2*	Schedule #3*		Schedule #4*		Schedule #5* summer and winter	Schedule #6*		Schedule #7*
					Summer (2)	Winter (2)	Summer (2)	Winter (2)		Summer	Winter	
Verdigris River TORONTO DAM SITE ATOKA, OKLA.	Kans.	271.5	-	12	-	-	-	-	1	12	12	12
NEEDS SHA DAM SITE NEEDS SHA, OKLA.	Kans.	222.8	-	-	16	10	6	6	-	16 (2)	19 (2)	7
FALL RIVER FALL RIVER DAM SITE FREDONIA, KANS.	Kans.	215.3	-	9	2	3	1	1	2	9	9	9
ELK RIVER ELK RIVER DAM SITE (Table Mound)	Kans.	197.9	3	9	-	-	-	-	3	9	9	9
Verdigris River Independence Coffeeville COLOMAN DAM SITE BLOW OOLOGAH	Kans. Okla.	195.0 185.0 190.8	6 6 (3)	24 24 (3)	7 40 (3)	3 17 (3)	27 45 (3)	9 15 (3)	6 6 (3)	24 40 (2) (3)	27 (2) 45 (2) (3)	24 24 (3)
Cane River HULAN DAM SITE SEFTLESVILLE	Okla.	78.5 17.7 146.0	4	10	10	3	14	4	4	11 (2)	14 (2)	10
Bird Creek Pawhuska Barnsdall	Okla.	63.5 145.4 111.0	- 1	- 6	4 11	2 3	5 14	2 4	- 1	4 (2) 11 (2)	5 (2) 14 (2)	2 6

Note: Flows to be provided except during unusually dry years occurring no oftener than once in ten years.
Eighty per cent of indicated flows, however, should be guaranteed during such unfavorably dry years.

- (1) Miles to mouth, Verdigris River.
(2) Average summer (May through October) flow. Variation from 64 to 127 per cent of figure shown. See table 11.
(3) The reach of the Verdigris River below Oologah Reservoir is remote from sources of pollution and is not used as the source of an important local water supply. Therefore, releases from this reservoir need not be governed by questions of pollution or local water supply.

In considering the question of required flows in the Verdigris River basin, three objectives have been considered: first, the "absolute minimum" (Schedule "A" Table 10) necessary for public water supply use; second, the "desirable minimum" (Schedule "B") necessary in conjunction with efficient sewage and industrial waste treatment plants to maintain stream water quality at a level suitable for all reasonable uses; and third, a "high minimum" (Schedule "C") which would not only maintain water quality but would permit certain reductions in the cost of sewage and industrial waste treatment.

In the present situation, any appreciable increase in low flows is desirable and of great value. Increases beyond absolute minimums are also desirable but a point is reached where benefits no longer balance costs and further water development is not justified.

In the present instance, a relatively small increase in flow (Schedule "A") such as 6 c.f.s. at Independence, Kansas, would assure an adequate quantity for public water supply use. At the present time, during dry periods, the cities find it necessary to restrict use of water. Despite such restriction, there is an ever-present possibility of a shortage with a resulting failure of sanitary facilities and fire protection. Under such circumstances a relatively minor increase in flow has considerable value. However, such a minor increase in flow would not correct the situation in which each city's water supply in turn is dependent on the reuse of the spent water supply or sewage of the city above. Such increases in flow would not be adequate for industrial uses, would not be adequate to appreciably assist industrial waste and municipal sewage treatment

plants in the abatement of pollution, nor would such flows be effective in flushing the stream clear of objectionable waters within a reasonable time following accidental spills of brine or taste-producing wastes.

Desirable minimums (Schedule "B") rather than absolute minimums (Schedule "A") should therefore be the objective of a water development program.

Public Water Supply Quantity. - In determining absolute minimum flows required for public water supply use as shown in table 10 (Schedule "A"), the largest water supply on the Verdigris River (Coffeyville, Kansas) and on each tributary governs the flow required in the individual stream. During dry periods, water consumption, as a rule, is higher than the annual average. For example, pumpage during the maximum month in a typical city may be 125 per cent of the average, and pumpage during the maximum day in small cities may be 200 per cent of the average. In regions subject to severe drouths, such as the Verdigris River basin, and with all restrictions removed, maximum pumpage, both monthly and daily, may be in excess of the typical figures given. There is also the matter of future growth. For these reasons, the absolute minimum flows required for public water supply use as shown in table 10 have been taken as approximately 200 per cent of the average consumption figures given in table 4. Flows indicated are required during all seasons of the year.

Public Water Supply Quality. - It has been the experience throughout the Verdigris River basin that during times of extreme low flow the quality of water available for public water supply use leaves much to be desired. Objectionable characteristics may be high chlorides, may be taste and odor due possibly to municipal and industrial wastes, and may

be taste and odor due possibly to growths of algae. Increasing low flows to a degree further than the absolute minimum will have the effect of decreasing the severity of chloride, taste and odor difficulties and decreasing the time over which such difficulties are experienced.

It is definitely not proposed to increase stream flows in the Verdigris River basin to such a degree that all the oil field brines produced can be discharged to streams and diluted sufficiently to be unobjectionable in public water supplies. Neither is it proposed to furnish adequate flows to dilute taste and odor producing oil refinery wastes sufficiently to render such wastes unobjectionable to public water supply use. The order of magnitude of flows required for such purposes is beyond the range of possibility when considering the water resources of the basin. An indication of what might be expected with uncontrolled discharge of brine can be drawn from an examination of the steady increase in annual average chloride results in table 7 prior to the time reinjection control measures were started in the past decade. A record of tastes and odors due to oil refinery wastes in the Verdigris River basin is not available. However, it is reported that the City of Claremore abandoned the Verdigris River as a source of water because of these tastes and odors. Furthermore, experience in other places indicates that a large degree of control of oil refinery wastes at the refinery is necessary if water supply tastes and odors are to be eliminated successfully. It is concluded that, regardless of the future of water conservation measures, it will continue to be necessary to depend on reinjection for the disposal of oil field brines and to depend on control measures at the refinery for the disposal of oil refinery wastes. Increased low flows will render less objectionable the minor quantities of wastes unavoidably escaping despite careful control activities and will reduce the length of objectionable time resulting from accidental spills.

The flow requirements for protection of water supply quality will depend on the quantities escaping, and as this cannot be determined, there is no rational method of determining such requirements. However, the superintendent or operator of each water supply system of any size in the basin was consulted and conversations relative to the frequency and severity of chloride and taste and odor difficulties assist in establishing reasonable figures for flows to protect water supply quality. It has been concluded that during an average or better than average year as far as low flows are concerned, no appreciable chloride or taste and odor difficulty is to be expected, while during a worse than average year some trouble may be expected, the severity depending upon the severity and length of the dry period. The flows indicated in table 10 as necessary for the protection of water supply quality have been taken as the two-year frequency low-flow month as shown in table 9. The one exception is on Bird Creek, where the three-year minimum month has been used as representing a more reasonable figure. The public water supply of Barnsdall is the only water supply affected.

The chloride content is independent of temperatures and, from the standpoint of controlling chloride concentration, the flows indicated are required during all seasons of the year. The question of seasonal flow variations necessary to reduce tastes and odors involves a number of factors. Some taste and odor-producing compounds in industrial wastes are attacked and rendered unobjectionable by biological activity, and such compounds are less objectionable in summer than in winter when biological activity is inhibited. Other compounds may be unaffected by

biological activity, and algae tastes and odors are created by such activity. Increased flows will have two important beneficial effects as regards tastes and odors throughout the year and these are, first, the taste and odor-producing compounds will be diluted, resulting in lower concentrations and less objectionable conditions and second, increased flows will flush out channel reservoirs in less time, thus reducing the objectionable period. After considering the various factors, it has been concluded that releases in the interest of improved water supply quality should be uniform throughout the year.

Industrial Water Supply Quantity. Requirements for industrial water supply are confined to oil refineries at Woodessa and Coffeyville, Kansas, and Barnsdall, Oklahoma. It is assumed that flows required for the oil refinery at Barnsdall will also be adequate for the chemical plant at Tallant, Oklahoma, concerning which only limited information was obtained.

According to information from the Ohio River Pollution Survey,* water consumption at 41 refineries averaged 770 gallons per 42-gallon

* Ohio River Pollution Control, House Document 266,
78th Congress, 1st Session, p.1178.

barrel of crude oil refined. This figure has been taken as reasonable and has been used in determining flows required for industrial water supplies as shown in table 10. From 80 to 90 per cent of the water used in an oil refinery is for cooling purpose and it is possible, by using cooling ponds, to reduce water consumption to a small fraction of the figures indicated in table 10. Industrial water supply needs as indicated are not therefore absolute minimums but can be considered desirable minimums (Schedule "B").

Pollution Abatement. - In the typical case of pollution from a city or industry entering a stream, the objectionable conditions resulting can be corrected in large measure by treatment, the degree or efficiency of treatment required being dependent on the size of the city or industry in relation to the minimum flow in the stream. For example, a moderate sized or large city on a small stream requires an elaborate treatment plant accomplishing a high degree of purification. On a larger stream, the same city or industry might well find that a partial treatment would suffice. It follows that if the flow in an outlet watercourse is increased, it may be possible for a partial treatment to abate pollution at lesser cost. Under such circumstances the savings in cost can quite justifiably be credited to the increase in flow as a benefit. This approach assumes that there is ample justification for correcting the pollution because of the benefits of a clean stream or that abatement of pollution is required by common law, state legislation or court decision.

When flows approach or reach zero, there arises a question as to the possibility of maintaining satisfactory stream conditions regardless of the degree of treatment used. As a rule the so-called "secondary" or "complete" treatment plant can safely guarantee a purification of 85 per cent, although average efficiencies may be much higher. Sewage or strong industrial wastes purified to a degree represented by 85 per cent may still depress dissolved oxygen to a level lethal to fish and bordering on actual odorous nuisance conditions. In addition, during times of heavy rain, accumulations of organic matter in sewers may be flushed out of branch sewers at a high rate in excess of the capacity of main collecting

sewers, so that the accumulated pollution is discharged from storm water overflows direct to the stream to form sludge banks capable of creating a nuisance during later periods of low flow. This situation is not unusual, a notable case being the Scioto River below Columbus, Ohio, where, despite unusually large intercepting sewers, storm water holding tanks and one of the most efficient treatment plants in the country, the pollution situation has not been wholly corrected. It follows that in the case of zero minimum flow streams, increased flows are highly desirable and valuable in that such flows will accomplish a pollution abatement that can be accomplished by no other means.

In the case of the Verdigris River basin, desirable minimum flows (Schedule "B") have been computed on the basis that each city not now so equipped will install and operate a secondary sewage treatment plant capable of guaranteeing an 85 per cent purification efficiency and that organic pollution from industrial wastes will be reduced 50 per cent during times of low flow by corrective measures in the plant, lagooning or treatment.

Because of the absence of laboratory determinations of actual rates of deoxygenation and reaeration in typical Verdigris River basin streams, low rates of both deoxygenation and reaeration (K_1 equals 0.1 and K_2 equals 0.1 in Streeter-Phelps formula*) have been assumed. Using these

* H. W. Streeter and E. B. Phelps. "A Study of the Pollution and Natural Purification of the Ohio River. III. Factors Concerned in the Phenomena of Oxidation and Reaeration." Public Health Bull. 146, U. S. Public Health Service (1925).

constants, it has been determined that in order to maintain a minimum dissolved oxygen of 3 p.p.m. or to provide sufficient oxygen for an

assured freedom from nuisance, a dilution of 4.5 c.f.s. per 1000 sewered population equivalent as discharged (based on 0.17 lbs. 5-day, 20°C. B.O.D. per capita per day plus freedom from sludge deposit-forming settleable solids) will be required at a water temperature of 25°C. (77°F.). If a more optimistic assumption is made of the reoeration constant (K_2 equals ^{.25} 0.025), a dissolved oxygen level of 5.0 p.p.m. or adequate to maintain fish life will be maintained.

The results of the Ohio River Pollution Survey* showed that in a

* Ohio River Pollution Control, House Document 206, 78th Congress, 1st Session.

relatively small stream, such as the Verdigris River and its tributaries, organic matter is stabilized at a rapid rate due probably to profuse biological growths on the bottom of the shallow stream. This creates a rapid demand on the dissolved oxygen of the stream but this is offset to a large degree by a rapid rate of reoeration. The result is that with equal concentrations of pollution a small and a large stream may have oxygen depressions of similar magnitude but the small stream will have recovered in a few miles while a large stream will require as much as 50 miles for a similar recovery.

Flows required for pollution abatement are much greater in the summer than in the winter. This is due to the fact that oxygen has decreased solubility in water at high temperatures, plus the fact that biological activity is greater at high temperatures. The flows shown in table 10 are to be considered average summer (May through October) flows. The

Table 11 - Verdigris River Investigation - Monthly Variations
in Required Flows.

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Month	Normal air temperatures U. S. Weather Bureau °F.	Relative flow required (1) per cent	Flows required (Schedule "B") c. f. s.			
			Verdigris River		Caney River at Bartlesville, Okla.	3rd Creek at Bernedall, Okla.
			At Neodesha, Kans.	At Coffeyville, Kans.		
January	34.9	30	7 (2)	24 (2)	10 (2)	8 (2)
February	37.6	30	7 (2)	24 (2)	10 (2)	8 (2)
March	47.9	40	7 (2)	24 (2)	10 (2)	8 (2)
April	59.9	62	10	25	10 (2)	8 (2)
May	66.4	77	12	31	10 (2)	8
June	75.8	109	18	43	11	12
July	80.1	127	20	51	13	14
August	79.9	127	20	51	13	14
September	72.5	96	16	38	10 (2)	11
October	60.7	64	10	26	10 (2)	8 (2)
November	47.7	39	7 (2)	24 (2)	10 (2)	8 (2)
December	37.3	30	7 (2)	24 (2)	11 (2)	8 (2)
Summer Average, May through October	72.6	100	13	40	11	11
Yearly Average	58.4	69	12	32	11	10

Note: Flows to be provided except during unusually dry years occurring no oftener than once in ten years. Eighty per cent of indicated flows, however, should be guaranteed during such unfavorably dry years.

- (1) For pollution abatement in per cent of summer average (May through October) flow.
- (2) Required flow governed by either public water supply quality requirements, industrial requirements, or both. During other months, required flow is governed by pollution abatement requirements.

monthly variation in flows required for Schedule "B" is shown in table 11.

It is to be noted that the requirements for pollution abatement will govern midsummer releases, whereas flows required for water supply quality protection or for industrial use or both will govern releases during the winter months.

Estimates of water requirements made at this early stage in the development of the water resources of the basin serve merely as a guide in the design and initial operation of the projects. However, with experience in operation, there is a possibility that flow adjustments may be permitted downward or required upward. An organization accepting the responsibility of regulating the flow in a stream presumably should maintain a record of pollution as well as other conditions in order that the natural waters may be used to the greatest advantage of all concerned.

Consideration has been given to the possibility of maintaining "high minimum" flows (Schedule "C"), which would accomplish all purposes of the desirable minimum flows (Schedule "B") and in addition would permit certain economies in sewage treatment. Such flows would have added value but on a lower scale as the needs are less urgent. In computing high minimum flows (Schedule "C"), it has been assumed that all cities not now supplied will provide primary sewage treatment. Existing sewage treatment plants will remain as at present. It is further assumed, as before, that industrial wastes will be reduced 50 per cent during times of low flow by corrective measures in the plant, lagooning or treatment. High minimum flows as shown in table 10 (Schedule "C") have been computed using deoxygenation and reoxygenation constants as already described.

Benefits

In accordance with the request of the District Engineer, brief consideration has been given to the question of monetary benefits resulting from proposed stream regulation in the Verdigris River basin. As the request is for approximate estimates only and as it was further requested that the time spent be limited, certain time-saving expedients have been followed. For example, unit per capita costs of tertiary sewage treatment units have been taken from previous reports prepared by the U. S. Public Health Service for the Tulsa District Engineer rather than prepare individual estimates for the cities involved. Also the per pound cost of reducing biochemical oxygen demand by secondary units of a "complete" treatment plant have been computed for a typical case and used in places where improvements are needed to existing plants rather than prepare estimates of construction and operating costs for expansions and improvements at the individual plants. However, it is believed that the preparation of more detailed treatment cost estimates would not change the final monetary benefit estimates to any great degree.

A summary of benefit estimates for the flow regulation summarized in table 10 is shown in table 12.

Previous Benefit Estimates. Paragraph 4, Sheet 27, Appendix 4 (unprinted) of the Corps of Engineers report on the Verdigris River in Kansas (H.D. 140, 76th Cong., 1st Session) computes the benefits of proposed regulation by the four reservoirs in Kansas plus the recreational and other benefits of the conservation pools to be \$137,500 per year, or the

Table 12 - Verdigris River Investigation - Summary of Water Supply and Pollution Abatement Benefits

Reservoir and Location	State	Mile (1)	Water Supply				Pollution Abatement			Total Benefits		
			Quantity benefits		Quality plus municipal quantity benefits, Schedule #3*	Schedule #3*	Schedule #3*	Additional benefits over Schedule #3*	Schedule #3*	Schedule #3*	Schedule #3*	Schedule #3*
			Municipal Schedule #1*	Industrial Schedule #2*								
Cologah Reservoir	Okla.	80	\$ 0	\$ 0	\$ 0	\$ 0	\$ 0	\$ 0	\$ 0	\$ 0	\$ 0	\$ 0
Four Kansas Reservoirs												
Frederia	Kans.	241.3	0	0	11,400	2,800	200	0	0	0	14,000	14,200
Neodesha	Kans.	219.0	3,800	1,800	10,900	2,300	1,800	0	0	0	14,800	12,370
Cherryvale	Kans.	201.4	0	0	12,300	0	0	0	0	0	12,370	12,300
Independence	Kans.	195.0	3,800	0	37,300	8,400	1,700	0	0	0	45,800	45,800
Coffeyville	Kans.	185.0	3,800	3,370	76,100	14,300	1,800	0	0	0	93,700	94,000
Nowata	Okla.	122.0	0	0	6,900	0	0	0	0	0	6,900	6,900
Total			11,400	4,900	163,300	27,500	3,600	0	0	0	165,600	166,500
Bulah Reservoir		174.7										
Dewey	Okla.	154.0	0	0	6,900	1,800	0	0	0	0	8,700	8,700
Bartlesville	Okla.	148.0	3,800	0	56,900	12,600	1,000	0	0	0	69,800	70,300
Collinsville	Okla.	93.9	0	0	6,000	1,400	0	0	0	0	7,400	7,400
Total			3,800	0	68,800	15,800	1,000	0	0	0	85,600	86,600
Bird Creek												
Pawnee	Okla.	145.4	0	0	0	4,200	0	0	0	0	4,200	4,200
Barnsdall	Okla.	111.0	0	1,100	6,000	1,300	1,000	0	0	0	8,400	8,400
Skiatook	Okla.	98.5	0	0	0	1,100	0	0	0	0	1,100	1,100
Total			0	1,100	6,000	5,600	1,000	0	0	0	13,700	14,700
TOTAL			\$ 15,200	\$ 6,000	\$ 228,900	\$ 50,000	\$ 5,900	\$ 0	\$ 15,300	\$ 234,900	\$ 234,900	\$ 234,900

(1) Miles to mouth of Verdigris River.

(2) Figures obtained by adding Pollution Abatement Schedule #3* column to Total Benefits Schedule #3* column.

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pro rata cost of the storage allotted for these purposes. As has already been pointed out in this report, the proposed regulation will result in improvements that can be accomplished in no other way and there is ample justification for the approach used.

In a memorandum dated December 9, 1942, D. V. McCarthy of the National Resources Planning Board expressed the opinion that the benefits would be in excess of the figure used and that \$200,000 per year would not be unduly high. Presumably this figure is based on judgment and a general knowledge of the basin rather than a detailed analysis, as no supporting data is mentioned. However, if any appreciable weight is given to the many intangible benefits involved, there appears to be no great objection to such a figure.

Public Water Supply If the public water supply problem in the Verdigris River basin were merely one of quantity, it is probable that the problems could be solved by the installation of additional channel dams impounding 100 to 200 acre-feet of water at Coffeyville, Independence and Neodesha, Kansas, and Bartlesville, Oklahoma. These cities already have channel impoundments but the capacities are so limited that shortages have occurred. Based on similar dams in the Grand (Neosho) River basin, it is estimated that four such additional dams would cost \$280,000. Assigning a 30-year life and $3\frac{1}{2}$ per cent interest to these channel dams, the annual cost for the four dams would be \$15,200. This can equitably be credited as a benefit to reservoir development capable of providing 6 c.f.s. at Independence and Schedule "A" flows as shown in table 10 in other streams of the basin. Of the total of \$15,200 benefit per year, \$11,400 can be credited to the four Kansas reservoirs and \$3,800 to Mulah reservoir.

Due to the shortcomings of the Verdigris River and its major tributaries as a public water supply from the standpoint of both quality and quantity, there has been considerable agitation in the cities using these streams to develop other sources, particularly impoundments on relatively small streams. A number of years ago the city of Claremore, Oklahoma, actually did abandon the river and now secures its water supply from an impoundment on Dog Creek, a minor tributary of the Verdigris River. Other cities have hired consulting engineers to prepare engineering reports on alternate sources. Estimates of original cost presented in three such reports, as shown in table 13, average \$60.00 per capita. The cost of

Table 13 - Verdigris River Investigation - Engineering Estimates for Proposed Independent Municipal Water Supply Developments.

City	1940 Population	Year of Report	Cost Estimate
Bartlesville, Okla.	16,267	1924	\$1,417,000
Nowata, Okla.	3,904	1938	126,000
Coffeyville, Kansas	17,355	1942	1,400,000

these projects, plus similar projects for other cities of appreciable size in the basin, is a measure of the benefits to public water supply use of flow regulation. To secure these benefits, flows indicated in table 10 as necessary to maintain quality (Schedule "B") are necessary, as the independent water developments presumably would solve quality problems as well as quantity problems. If Schedule "B" flows are provided, Schedule "B" benefits are substituted for Schedule "A" benefits rather than added to them.

Basing water supply project costs on the per capita figure of \$60.00 in cities where engineering estimates are not available, and assigning a life of 30 years and an interest rate of $3\frac{1}{2}$ per cent to such projects, the annual benefits in the basin total \$226,000, of which \$153,100 is a benefit to the four Kansas reservoirs, \$69,800 is a benefit to Mulah Reservoir, and \$6,000 is a benefit to a possible project on the upper reaches of Bird Creek. Details of the estimates are shown in table 14. Of the total benefits indicated, 61 per cent are based on engineering estimates.

Industrial Water Supply The following is quoted from Paragraph 58, Sheet 25, Appendix 4 (unprinted) of the Corps of Engineers report on the Verdigris River in Kansas (H.R. 440, 78th Cong., 1st Session) dated July, 1939:

"During periods of such low flow, the water passing the Coffeyville municipal water supply dam is insufficient to meet the needs of the two refineries located at Coffeyville. It is therefore necessary for these refineries, during such seasons, to recapture the water that would otherwise escape with refinery wastes to augment their supply. The treatment of waste water for recirculation is estimated by the refineries to add \$60 per day to the cost of treating their water supply during the period of the shortage."

The flow at Coffeyville, Kansas, according to Chart 2 of the above Appendix (assumed the same as Independence, Kansas), is less than the 24 c.f.s. estimated as required at the refineries at Coffeyville on an average of 55 days per year.

Table M₁ - Verdigris River Investigation - Estimates of
Municipal Water Supply Benefits from Flow
Regulation by Proposed Reservoirs (Schedule "B")

Reservoir and Location	State	Cost of independent water development	Annual benefit (1)
Geologah Reservoir	Okla.	\$ 0	\$ 0
Four Kansas reservoirs			
Fredonia	Kans.	210,000 (2)	11,400
Hoodosha	Kans.	200,000 (2)	10,900
Cherryvale	Kans.	100,000 (2)	10,300
Independence	Kans.	600,000 (2)	37,500
Coffeyville	Kans.	1,400,000 (3)	76,100
Nowata	Okla.	126,000 (3)	6,000
Total		2,816,000	153,100
Hulah Reservoir			
Dewey	Okla.	126,000 (2)	6,900
Bartlesville	Okla.	1,047,000 (3)	56,000
Collinsville	Okla.	110,000 (2)	6,000
Total		1,283,000	69,800
Bird Creek			
Burnsdall	Okla.	110,000 (2)	6,000
TOTAL		\$ 4,209,000	\$ 228,900

(1) Cost of development x 0.05437 based on 7-1/2 per cent interest and 30-year life.

(2) Based on \$60.00 per capita.

(3) Engineering estimates.

45.

If the necessary flow were provided (Schedule "B"), the benefits would be \$3300 per year. This represents only part of the benefits, as many of the benefits of an adequate supply of water for industrial use are of an intangible nature. If the benefits at other refineries are taken as proportional to their size, benefits at Hedgesha, Kansas, are \$1600 per year and at Barnsdall, Oklahoma, are \$1100 per year. These latter two benefits are not correct except in order of magnitude, but the small size of the benefits appears not to warrant more detailed studies of flow frequencies.

Pollution Abatement In determining monetary benefits to pollution abatement, it is presumed that organic and other types of sewage and industrial waste pollution in the Verdigris River basin will be controlled either by treatment and other corrective measures alone or a combination of such measures with dilution by increased river flows. There is no thought of correcting pollution by dilution alone or even of correcting pollution largely by dilution. Treatment and, in the case of industrial wastes, treatment plus corrective measures in the plant, will remain the principal method of correcting pollution. In the case of Schedule "B" flows it is assumed that effective secondary treatment capable of dependable efficiencies of 85 per cent and average efficiencies of 90 to 95 per cent will be installed at all cities. It is also assumed that industrial wastes will be reduced 50 per cent. An efficiency of 50 per cent cannot be considered satisfactory and would not be approved by state regulatory authorities. It is not an ultimate objective but rather a practical immediate objective attainable at reasonable cost.

In the case of Schedule "C" flows it is assumed that present municipal sewage treatment plants will continue and that cities with less than effective sedimentation (35 per cent efficiency) of sewage will install the necessary plant to attain this relatively low efficiency. This again is not an ultimate objective and would not be approved by state regulatory authorities. Should Schedule "C" flows be provided, an effort to secure an 85 per cent purification efficiency would still be justified to further improve the standard of quality in the streams. In the case of Schedule "C" flows it is also assumed that industry will accomplish a 50 per cent reduction of industrial waste pollution.

As has been pointed out, dilution will accomplish results not possible when treated wastes are discharged to a dry watercourse, and therefore any estimate of a high degree of treatment to accomplish results equivalent to a specified dilution will approach the benefits resulting from flow regulation but will never quite reach them, and the resulting benefit estimates are therefore to be considered minimums.

In estimating benefits to pollution abatement from Schedule "E" flows, supplemental treatment, as tertiary units, to produce a stream improvement equivalent to that produced by such flows has been taken as intermittent sand filters. Unit per capita costs have been taken as determined in connection with the U. S. Public Health Service Grand (Neosho) River Investigation as presented in a report dated August, 1940. The following is quoted from that report:

"Design figures used in the computations were based on consideration of influent waste to be treated, local conditions affecting cost, actual experience on similar problems in other sections and policy

requirements of the Kansas State Board of Health in approving actual plans. Sand filters were designed on the basis of a 3-foot depth and loadings of 150,000 gallons per acre per day (loading rates based on policy requirement of Kansas State Board of Health). Price of filter sand was determined at \$2.00 per cubic yard, f.o.b. destination. Chlorination of sand filter effluents was excluded from the designs inasmuch as the proximity of intakes to outfalls is such that chlorination of treatment plant effluents appears indicated regardless of the degree of treatment."

From the same report, additional cost of operation is estimated to be \$15,000 per year for a population of 61,000, or \$0.24 per capita per year. Assigning a life of 20 years and an interest rate of 3-1/2 per cent to the supplementary treatment units, annual benefits, as detailed in table 15, in the entire basin, total \$50,000, of which \$27,400 is the benefit to the four Kansas reservoirs, \$15,800 is a benefit to Hulah Reservoir, and \$6,600 is a benefit to a possible project on the upper reaches of Bird Creek.

In estimating benefits to pollution abatement from Schedule "C" flows, treatment of sewage by effective sedimentation is assumed at all cities not now provided with such facilities, and additional costs beyond that point to increase efficiencies to 85 per cent has been taken as \$1.40 per population equivalent removed per year. For example, the city of Neodesha, Kansas, has a secondary treatment plant but, because of shortcomings in the plant and its operation, the State of Kansas has expressed the opinion that the purification efficiency is about 40 to 50 per cent rather than 85 per cent. In other words, the plant is judged to reduce the sewered population equivalent by 1,200 ($2,700 \times 0.45$) rather than by 2,300 ($2,700 \times 0.85$). The average annual cost including interest, amortization and operation of additional facilities to remove the 1,100 sewered population equivalent difference has been computed as 1,100 times \$1.40, or \$1,500 per year.

Table 15 - Verdigris River Investigation - Estimates of Pollution Abatement Benefits from Flow Regulation by Proposed Reservoirs (Schedule "B")

Reservoir and Location	State	Cost of supple- mentary waste treat- ment	Interest and amorti- sation (1)	Opera- tion	Annual benefit
Oologah Reservoir	Okla.	\$ 0	\$ 0	\$ 0	\$ 0
Four Kansas Reservoirs					
Fredonia	Kans.	27,000	1,900	700	2,600
Hoodesha	Kans.	23,000	1,600	700	2,300
Independence	Kans.	85,000	6,000	2,400	8,400
Coffeyville	Kans.	145,000	10,200	4,100	14,300
Total		280,000	19,700	7,900	27,600
Hulah Reservoir					
Dewey	Okla.	18,000	1,300	500	1,800
Bartlesville	Okla.	128,000	9,000	3,600	12,600
Collinsville	Okla.	15,000	1,000	400	1,400
Total		161,000	11,300	4,500	15,800
Bird Creek					
Pawhuska	Okla.	43,000	3,000	1,200	4,200
Barnsdall	Okla.	13,000	900	400	1,300
Skiatook	Okla.	11,000	800	300	1,100
Total		67,000	4,700	1,900	6,600
TOTAL		\$508,000	\$35,700	\$14,300	\$50,000

(1) Cost of treatment x 0.07036 based on 3-1/2 per cent interest and 20-year life.

The derivation of the \$1.40 annual cost per sewered population equivalent removed by secondary treatment units using Ohio River Pollution Survey* cost data is shown in table 16. .

* Ohio River Pollution Control, House Document 226, 76th Congress, 1st Session.

If Schedule "C" flows are provided, the additional annual benefits over those resulting from Schedule "B" flows total \$5,900 for the basin, of which \$3,900 is a benefit to the four Kansas reservoirs, \$1,000 is a benefit to Mulah Reservoir, and \$1,000 is a benefit to a possible project in the upper reaches of Bird Creek.

Intangible Benefits In addition to the benefits to water supply and pollution abatement for which annual values have been estimated, there are numerous benefits, equally real and justifying expenditures of magnitude but which, because of their nature or other limitation, cannot be monetarily evaluated. These benefits, referred to as intangible, include benefits to agricultural use including stock watering, benefits to aquatic and wild life and to recreation, and indeterminate values to the public health. These benefits are competently discussed in Paragraphs 59, 62 and 63 of Appendix 4 (unprinted) of House Document 440, 76th Congress, 1st Session, as follows:

Table 16 - Verdigris River Investigation - Unit Cost of Reducing
Pollution by Secondary Treatment Units

Design population 10,000

Treatment	Estimated cost	Interest and amortization (1)	Operation and Maintenance	Total annual charges "X"
Primary	\$104,000	39,030	4,800	\$13,830
Secondary (2)	149,000	12,940	8,000	20,940
Difference	45,000	3,910	3,200	7,110

Treatment	Purification efficiency, per cent	Sewered population equivalent removed "Y"	Total annual charges per sewer population equivalent removed "Z" "W"
Primary	35	3,500	----
Secondary	85	8,500	----
Difference	50	5,000	31.40

(1) Cost x 0.08683 based on 3-1/2 per cent interest and 15-year life.

(2) Secondary treatment consists of treatment by primary followed by secondary "units".

"59. In addition to the benefits to municipal and industrial water supply derived by the dilution of polluting wastes, there would be some benefit to rural livestock owners who are dependent upon the rivers for livestock water supply. Cattle and hogs have been killed by drinking river water in times of low flow when the concentration of industrial wastes was excessive.

"62. The reservoir plans discussed in the main report provide for a permanent pool in each of the proposed reservoirs. These pools should prove attractive as resting places to migratory waterfowl using the central flyway and as recreational centers for the large population within a radius of at least 100 miles, since there are few bodies of water available for such use within that radius. It is estimated, on the basis of hydrology records at Independence, that the Toronto and Noodosha Reservoirs will be in operation an average of 17 days and that the Fall River and Elk City (Table Mound) Reservoirs will be in operation an average of 16 and 19 days, respectively, annually, for flood control. The operation of these reservoirs for flood control for so few days per year should not seriously hinder their use for recreational purposes.

"63. Recreational and wildlife benefits are of such a nature that no satisfactory method of evaluating them has been found. Among other things, these benefits include enhanced property values, created or increased markets for farm products and sporting equipment, gasoline, etc., the reduction of nervous and mental disorders, disease, and juvenile delinquency, and the value of the game or fish taken. They accrue to the facility owners, the patrons, and to the general public."

As previously discussed in this report, during periods of drouth the municipal water supplies of the lower cities in the Verdigris River basin are dependent on the reuse of the spent water supply or sewage from upstream communities. Aside from an esthetic sense, which alone is enough to condemn the situation, the practice of depending on such water supplies, despite artificial treatment and purification measures, creates a public health problem of serious concern.

